A Risk Management Model of Urban Areas near Ammunition Storage

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Abstract

According to safety standards - buildings, civil facilities and heavily used routes can be located at Inhabited Building Distances (IBD) that are termed only as separation distances. Minor injuries and unstrengthened buildings damage not exceeding five percent of their Reinstatement Value are expected. Indirect consequences of Ammunition and Explosives explosion event are not considered at all in the standards. In contrary, safety demands for cases where explosion of Ammunition or Explosives is initiated or caused by hostile activities must be much greater than IBD. In order to prevent casualties or injuries to the public they should be either protected, or being moved beyond a safety distance, much greater than the IBD. The standards usually take the low marginal probability, i.e. 10^{-6} per annum, and by that assume that accidental events rarely occur. Risk expectancy gives some legitimacy for these relatively short distances. On the other hand, in a circumstance where the probability of an accidental explosion is greater, and ammunition is located near urban areas, the standards might be risky and inappropriate. A risk management model for the analysis and assessment of risks encompassing physical and economic consequences is proposed. Using DDESB- TP14-SAFER methodologies and knowledge, the model estimates a conversion between protective measures and different ammunition quantities vs. IBD for a given site data. A case study was carried out for a given town and a highway located at a permitted IBD of less than 1,000 meters from all kinds of PES (Potential Explosion Site): open storage or an earth covered magazine which contains 100 tons of Net Explosive Weight of HD (Hazard Division) 1.1. The study elucidates that under the conditions given for Israel's urban area and building standards, protection of the exposed site must be upgraded according to Israel Home Front Command, WBDG, FEMA recommendations, i.e. window strengthening, and to consider updating IBD formulae.

Keywords: Ammunition and Explosives, Critical Infrastructure, Probabilistic Risk Assessment, Inhabited Building Distance.

Introduction

According to various ammunition safety standards and manuals (DOD 6055.09,4145.24-M, AASTP-1, and Israeli MoD standard 4145) Inhabited Buildings and Critical Infrastructures (CI) can be located at least at Inhabited Building Distances (IBD). These distances are determined as separation distances and not as safety distances, due to the fact that damages and even risk to people might occur are not considered. The article is focused in large quantity (100 tons) of above ground ammunition storage of Hazard Division 1.1 (Mass detonation). It was found that there are some important differences in the IBD demands between US-DoD, European-NATO, and Israeli AE (Ammunition and Explosives) storage standards and manuals. US-DoD [DOD 6055.09,4145.24-M] permits 6.2-8.3 kPa as peak incident overpressure (scaled distance K varies between 15.87 to

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14. ABSTRACT

According to safety standards - buildings, civil facilities and heavily used routes can be located at Inhabited Building Distances (IBD) that are termed only as separation distances. Minor injuries and unstrengthened buildings damage not exceeding five percent of their Reinstatement Value are expected. Indirect consequences of Ammunition and Explosives explosion event are not considered at all in the standards. In contrary, safety demands for cases where explosion of Ammunition or Explosives is initiated or caused by hostile activities must be much greater than IBD. In order to prevent casualties or injuries to the public they should be either protected, or being moved beyond a safety distance, much greater than the IBD. The standards usually take the low marginal probability, i.e. 10-6 per annum, and by that assume that accidental events rarely occur. Risk expectancy gives some legitimacy for these relatively short distances. On the other hand, in a circumstance where the probability of an accidental explosion is greater, and ammunition is located near urban areas, the standards might be risky and inappropriate. A risk management model for the analysis and assessment of risks encompassing physical and economic consequences is proposed. Using DDESB- TP14-SAFER methodologies and knowledge, the model estimates a conversion between protective measures and different ammunition quantities vs. IBD for a given site data. A case study was carried out for a given town and a highway located at a permitted IBD of less than 1,000 meters from all kinds of PES (Potential Explosion Site): open storage or an earth covered magazine which contains 100 tons of Net Explosive Weight of HD (Hazard Division) 1.1. The study elucidates that under the conditions given for Israel's urban area and building standards, protection of the exposed site must be upgraded according to Israel Home Front Command, WBDG, FEMA recommendations, i.e. window strengthening, and to consider updating IBD formulae.

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19.84 m/kg$^{1/3}$), and it does not determine any difference between common building or Critical Infrastructure (i.e. hospital, Power Plants, Communication facilities, highly populated facilities such as schools, convention centers, etc). It is clear that dynamic break of typical window glazing might cause major injuries. On the other hand, NATO manual [AASTP-1, Edition 1] determines special IBD's for Vulnerable Buildings and Public Important (highly occupied curtain wall building, schools, hospitals, etc.). For common inhabited buildings a maximum of 5 kPa (K=22.2 m/kg$^{1/3}$) side on overpressure is permitted, however for Vulnerable Buildings and Public Important it is limited to 2-3 kPa (K varies between 33.3 to 44.4 m/kg$^{1/3}$). It means that for the same PES, NATO requires separation distance 1.5 times, 2 times, or even more than twice the DoD demands. The Israeli MoD standard 4145 generally has the same demands as the US manuals 6055.09 and 4145.24-M. Its IBD exception is rigorous separation distances for densely populated areas according to [AASTP-1], i.e. separation distance K=22.2 m/kg$^{1/3}$ which means less than 5 kPa side on overpressure. None of the standards suggest structured methods or procedures for the assessment and management of risks for cases of more ammunition than is allowed, or for the case of existing nearby Critical Infrastructure, etc.

The article proposes a new Explosion Risk Analysis (ERA) method that combines Probabilistic Risk Assessment of Critical Infrastructures using Fault-Tree-Analysis and Decision-Trees for the assessment of risks expectancy caused by above ground Ammunition or Explosive storage. The main physical effect of an explosion which governs the higher IBD is blast over pressure. It is analyzed and quantified in terms of economic means (fatalities, injuries, damage, etc.) based on a critical infrastructure analysis, a hospital. The other effects: fragments, ground shock, debris are also discussed. Based on TP14, SAFER for blast-glass injury it was found that glass fragments resulted from the blast will create the most serious consequences. Hence, an upgrading of the windows to protected windows according to Israel Home Front Command, WBDG, FEMA recommendations plus protection improvements of end fixtures, which can guarantee zero injury was suggested and analyzed. The probabilities of accidental or terror events were assumed, based on case history and threat scenarios using known data. Two main alternatives are compared: the hospital as it is, and the upgraded protected hospital.

Definition of Critical Infrastructures

Critical Infrastructures (CI) consist of those physical and information technology facilities, services and assets which, if disrupted or destroyed, would have a serious impact on the health, safety, security or well-being of citizens. Critical Infrastructures are organizational and physical structures and facilities of such vital importance to a nations society and economy that their failure or degradation would result in sustained supply shortages, significant disruption of public safety and security, or other dramatic consequences (Moteff et al. 2003; Gheorghe et al. 2007). Infrastructures are crucial in sustaining minimum operation of a society and its government. The most critical ones are:

- Transportation
- Telecommunication and information
- Energy (electricity, gas and power plants) and water
- **Hospitals and healthcare facilities**
- Public facilities such as schools and governance buildings.

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Background

This following paragraphs review the state-of-the-art in risk analysis and management in Critical Infrastructures (CI).

a. Probabilistic Risk Assessment (PRA)

PRA has recently become increasingly important in dealing with Information and IT security. The implementation of PRA to solve Critical Infrastructures employs Risk Management (RM) framework advanced RM tools for Decision Making, and Implementation probabilistic risk assessment tools. (Haimes and Barker, 2009; Haimes, 2009). Probabilistic Risk Analysis (PRA) is a systematic and comprehensive methodology to assess risks associated with complex engineering technological systems. Consequences are expressed numerically (e.g., the number of injured or casualties) and the likelihood of occurrence is expressed as probabilities or frequencies (probability density function i.e., the number of occurrences or the probability of occurrence per unit time). The expectancy of risk is the loss expectancy: the sum of the products of the consequences multiplied by their probabilities. PRA is implemented using Fault Tree Analysis and Decision Trees.

b. Fault Tree Analysis (FTA)

This is a deductive procedure for determining the various combinations of hardware and software failures, and human errors that could result in the occurrence of specified undesired events (referred to as top events) at the system level. The main purpose of FTA is to evaluate the probability of the top event using analytical and statistical methods. The analysis follows two stages: qualitative analysis of the logical relations between the hardware composites of the systems according to logical gates and quantitative analysis that implements probabilities of basic events and logical gates to explore the probability of the occurrence of the top event. FTA may be implemented for decision making through Binary Decision Diagrams (BDD), and Markov Chains (Frohwein, et al.1999; Sinnamon and Andrews, 1996).

c. Failure Mode and Effects Analysis (FMEA)

FMEA was originally developed in the United States Army in 1949 and titled MIL-P-1629; it was helpful in avoiding preventable failures. Since then, FMEA has been used as a reliability evaluation technique to determine the consequences of system and equipment failures. FMEA is an analytic approach that identifies potential failure modes in a system, determines their effect on the operation of the system, and identifies actions to mitigate the failures. It also helps in exploring critical design chains or critical process characteristics that require particular measures to prevent or detect failure modes (Gofuku et al. 2006).

d. Failure Mode and Effects Critically Analysis (FMECA)

FMECA is an extension of the FMEA method. In addition to the basic FMEA, it includes a criticality analysis, which is used to chart the probability of failure modes against the severity of their consequences. The result highlights failure modes with

relatively high probability and severity of consequences, allowing remedial effort to be directed according to the highest effectiveness. FMECA is typically performed as part of a design project, to eliminate failure modes with high severity and probability, and to reduce as much as possible those with high severity and/or probability (Saglimbene, 2009).

Research Method

The research method follows four principal phases that combine the basic methodologies:

(I) Development of alternative design of the structure: protected and unprotected structure. Protected structure referred to the skeleton, then exterior envelope and the interior finishing of the facility to protect the occupants of the facility from shock waves, debris of concrete and glazing and design the interior finishing of the building (e.g. ceiling panels) in such a way that they will prevent injuries in the case of an explosion event. The output of this stage was Reinstatement Values of protected and unprotected psychiatric hospital.

(II) The second stage was carried out with the SAFER software – Analysis of the effects of given explosive event and IBD on the facility: psychiatric hospital located 1,000 meters from the site. Analysis followed TP14 SAFER methodology with the following assumptions.

(III) The outputs of the SAFER simulation analysis were quantified to assessment of number in injures according to the total number of occupants in the building. In addition to this the damage to the facility was assessed based on the TP 14.

(IV) The final stage of the analysis includes Probabilistic Risk Assessment: The risk expectancy of the facility was assessed by examination of the total risk expectancy with respect to the probability of an Ammunition Explosion event. Ammunition and Explosive (AE) annual Risk is estimated by the following traditional risk equation:

AR=P·R [1]

Where:

AR – Annual Risk Expectancy associated with an Ammunition Explosion event [$];

P - Probability/Likelihood of an Ammunition Explosion event;

R- Total costs of Consequence of an Ammunition Explosion event for a given design alternative [$/sq.m.].

The Present Value of the Risk expectancy along the facility life cycle is determined by the following expression [2]:

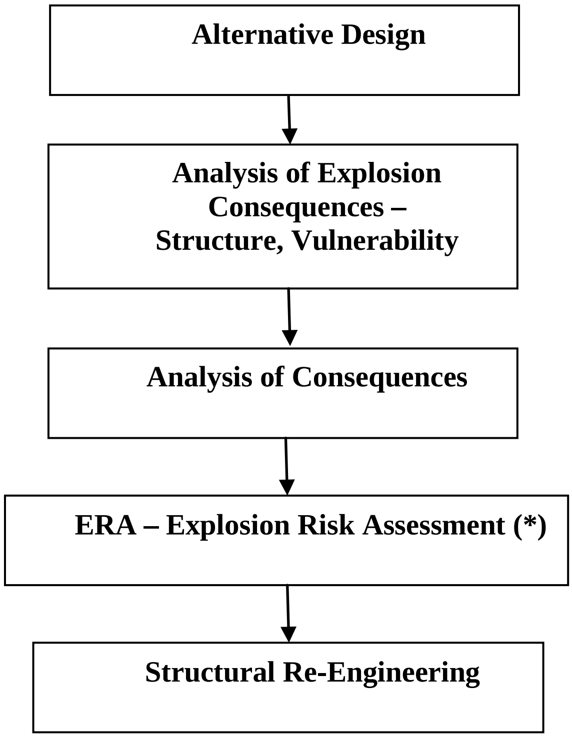
RPV=AR·UPV(i,lc) [2]

Where,

RPV – Present Value of Risk expectancy;

UPV(i,lc) – Present Value of Uniform series for annual effective discount rate (i) of 5% and building life cycle (lc) of 50 years;

The total cost associated with a design alternative is assessed using a decision tree in which the expectancy of risk is summed with Reinstatement Value of the design alternative.



(*) P.R.A. – Probabilistic Risk Assessment

Figure 1: Flowchart of the research method

Overview of the Research Project

Ammunition and Explosives - AE are being stored by various organizations and industries. Due to an accident, terror event or war activities the stored AE might explode, while causing severe hazards to structures Critical Infrastructure, and occupants. A review of various AE storage standards and manuals (US, NATO, Israel) for the case of NEQ (Net Explosive Quantity) of 100 tons of TNT, Hazard Division - HD 1.1 (Mass Explosion) was carried out, when there is a close urban area with Critical Infrastructure (CI), i.e. a hospital.

The case study included two alternative PES: Open storage and Standard Earth Covered Magazine (ECM). The PES is located according to US and Israel standards just 800 to 1200 from peripheral areas of a city. The explosion effects and consequences i.e. blast, fragments, and ground shock were analyzed by using various computer codes, (CONWEP, BEC, EBLAST), and literature formulas and diagrams. Sensitivity analyses to NEQ of 80, 100, and 120 tons of TNT and for distances of 800, 1000, and 1200 meters had been conducted.

The main focus of the research was a study of the vulnerability of an existing hospital as is (unprotected), and as an upgraded protected hospital with protective means: upgraded protected structure, upgraded protected windows (applied window film, catch bar) and doors, and strengthened end fixtures. The objective was to learn the consequences and risks from accidental explosion near a city, mainly on Critical Infrastructure: a hospital, and whether a protective upgrade can be beneficial along the hospital life cycle.

In the following figures and tables the research work and results are described:

Fig. 2 shows the area of explosion, with radii of 800, 1000, 1200m from the hypothetical PES. Critical Infrastructures at the ES are shown at Fig. 3: hospital, gas stations, and electric transformation station.

In Table 1 the Quantity – Distances demands (Q-D formulas) and peak over-pressure for HD1.1 IBD- Inhabited building distances are presented for the various standards. For US DoD 6055.09STD, 4145.26-M the IBD are required for all kinds of inhabited structures, buildings, and facilities. They do not have any special concern to CI nor weak construction, i.e. curtain wall structures.

Table 2 presents the NATO manual: AASTP-1 defines enlarged IBD in case of vulnerable construction and public importance. The overpressure is 2-3 kPa and the Q-D is 1.5-2 times in relation to regular structures. It means that CIs of the case study, according this manual, would have been placed at double distance from the PES.

NATO manual is also unique in the determination of ground shock and motions as shown in Table 3. The latter determination has no effect for the case study as a distance of 800 meters is much beyond the ground shock restrictions.

Table 4 presents calculated DoD IBDs for two alternative PES (Potential Explosion Site): a standard ECM and a PES as an open storage for 80, 100, and 120 tons of NEQ. The distances range between 656.2m to 1020.8m. It means that according to DoD standards the ES of the case study is possible.

Table 5 presents the Israeli MoD IBDs for normal building under 6 building units or apartments per 1,000 sq. m. For more populated buildings the IBD for 80, 100, and 120 tons should be $D=22.2Q^{1/3}$=956.6, 1030.4, 1095.m respectively. It means again that the ES of the case study is possible. The results are the same as in Table 6, since the Q-D formula is based on NATO manual for regular inhabited buildings.
According to NATO manual ECM as PES it is not allowed to be with its front side toward IBD, as in the DoD and in the MoD standards. Nevertheless, in all standards open storage with 100 tons is allowed to be located at about 1,000 meters from inhabited building.

In Table 7 blast parameters for 80, 100, and 120 tons NEQ in open storage and 100 tons NEQ also in ECM are presented according to CONWEP and BEC codes. Since PES can be open storage or ECM we have used the open storage blast parameters for the next steps.

Table 8 shows that according to BEC and 6055.STD that for the 100 tons and IBD of 1,000 meters and even for larger distances 100% of the ordinary windows (window area greater than 0.372 sq. m.) will be broken.

In Fig. 4 the gas station is shown. The structure was analyzed according to Israeli Concrete code IS466. It was found that structural failure is not expected, but in all NEQ from 80 Tons and above people are expected to be seriously injured by glass fragments from the large glazing windows. Fuel installation should be checked to avoid spilling and ignition.

In Fig. 5 the hospital is shown. The architectural layout plans were given, yet the structural drawing were not found. The analysis was based on observation and on the minimum values of IS466. The skelton construction consists by reinforced concrete columns, roof, floors and CMU (Concrete Masonry Units) walls.

It was found that the structure can resist the dynamic overpressure with minor damage. The hospital occupants are expected to be heavily injured because of glass fragments. All the windows will be broken.

According to TP14, SAFER methodology the number of injured occupants was estimated as presented in Tables 10 and 11. The most serious estimation based on Fig. 6, is that 10% of the occupants will have serious injuries.

Due to various explosion probabilities between 1e-6 to 1.5e-3, which are based on TP14, SAFER, and mainly on Israeli circumstances (terror, wars) the reasonable annual probability of event is 1e-4 or above.

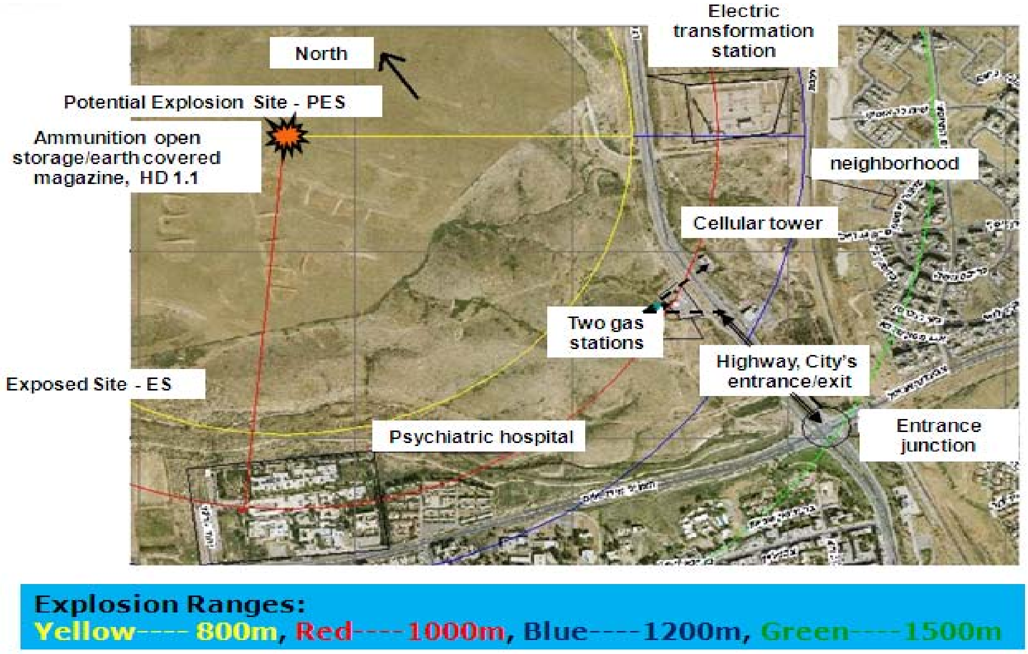


Fig. 2: The Hypothetical area of explosion

Fig. 3: Buildings and Facilities near the PES

Table 1: Quantity – Distances Demands and Peak Over-Pressure for HD1.1
IBD- Inhabited building distances (*)

High Traffic Density: If routes have 10,000 or more cars per day then IBD criteria is required

Ammunition Storage Standard, Manual	6055.09STD, 4145.24-M *for all buildings*	NATO AASTP-1 *for regular buildings*	Israel MoD Standard 4145 *for regular buildings* (**)
Blast Peak Overpressure	6.2-8.3 kPa [0.9-1.2 psi]	5 kPa [=0.05bar=0.7psi]	6-8.5 kPa [0.85-1.2 psi]
Quantity (Weight) - Distance Formulas for IBD	Distance From PES: $15.87Q^{1/3}$-$19.84Q^{1/3}$[kg,m] $40W^{1/3}$ ft - $50W^{1/3}$ [lb,ft] W< 100,000 lbs [45,400kg] → $40W^{1/3}$ [lb,ft] [$15.87Q^{1/3}$] [kg,m] W> 250,000 lbs [113,400kg] → $50W^{1/3}$ [lb,ft] [$19.84Q^{1/3}$] [kg,m]	Distances from Open Stacks and Light tructures $22.2\ Q^{1/3}$[kg,m] Distances from Earth Covered Magazines ECMs: Side=$18.0Q^{1/3}$[kg,m] Rear=$14.0Q^{1/3}$[kg,m] Front is not an option	Distance From PES: $16Q^{1/3}$-$20Q^{1/3}$ [kg,m] Q< [45,400kg] → $16Q^{1/3}$[kg,m] Q> [113,400kg] → $20Q^{1/3}$[kg,m]

(*) According to all standards for large amounts of NEQ Blast Over-Pressure governs, rather than fragment or debris.
(**) For 6 or less building units or apartments per 1000 square meter, otherwise, $D=22.2Q^{1/3}$ is required.

Table 2: NATO enlarged IBD according to vulnerable construction and public importance

Blast peak overpressure	2 kPa- 3 kPa = 0.02-0.03[bar] = =0.28-0.43[psi]
Quantity-Distance Formula	$33.3\ Q^{1/3}$ to $44.4\ Q^{1/3}$

According to page I-3-13 for schools and hospitals, IBD > $44.4Q^{1/3}$

Table 3: Quantity – Distances for HD1.1, IBD- Inhabited building distances
Due to Fragments, Debris, and Ground Shock & Motions

Parameter	Ammunition Storage Standards		
	6055.09STD 4145.26-M	NATO AASTP-1	Israel MoD Standard 4145
Fragments, Debris	1 hazardous fragment with energy of 78lb*ft at each 56 square meter (600 square ft.), Minimum distance 400 m.		
Ground Shock & Motions	No Restriction	Restricted, i.e. for dry sand: D(tamped charge) $=\mathbf{5.5Q^{1/3}}$ D(loading density≤50kg/m³)$=\mathbf{2.8Q^{1/3}}$	No Restriction

Table 4: IBD for NEQ 80, 100, 120 tons, HD1.1 according to DoD

DoD 4145.26-M, March 13, 2008
same as: *DoD 6055.09-STD, February 29, 2008*

Table AP2.T1. HD 1.1 IBD and PTRD (Table C9.T1.) (continued)

NEWQD	IBD From:			
	ECM			Other
	Front[1,2]	Side[1]	Rear[3]	PES[4]
(lbs)	(ft)	(ft)	(ft)	(ft)
[kg]	*[m]*	*[m]*	*[m]*	*[m]*
100,000	1,625	1,625	1,250	1,857
45,359.0	*495.0*	*495.0*	*381.0*	*565.6*
150,000	2,177	2,177	1,804	2,346
68,038.5	*663.5*	*663.5*	*550.0*	*715.2*
200,000	2,680	2,680	2,469	2,770
90,718.0	*816.8*	*816.8*	*752.5*	*844.4*
250,000	3,149	3,149	3,149	3,151
113,397.5	*959.8*	*959.8*	*959.8*	*960.4*
300,000	3,347	3,347	3,347	3,347
136,077.0	*1,020.3*	*1,020.5*	*1,020.5*	*1,020.5*
500,000	3,969	3,969	3,969	3,969
226,795.0	*1,209.9*	*1,209.9*	*1,209.9*	*1,209.9*

Notes for Table AP2.T1.:

1. 100,000 lbs < NEWQD ≤ 250,000 lbs: $d = 0.3955NEWQD^{0.7227}$ → d(NEW =220,458.6lb) =876.7m
45,359 kg < NEWQD ≤ 113,398 kg: $d = 0.2134NEWQD^{0.7227}$ → d(NEQ =100,000kg) =876.4m

ECM Front or Sid
distance towards Inhabited Buildings

3. 100,000 lbs < NEWQD ≤ 250,000 lbs: $d = 0.004125NEWQD^{1.0898}$ → d(NEW =220,458.6lb)=836.8m
45,359 kg < NEWQD ≤ 113,398 kg: $d = 0.002976NEWQD^{1.0898}$ → d(NEQ =100,000kg) =836.8m

ECM Rear
distance towards Inhabited Buildings

4. 100,000 lbs < NEWQD ≤ 250,000 lbs: $d = 2.42NEWQD^{0.577}$ → d(NEW =220,458.6lb)=893.2m
45,359 kg < NEWQD ≤ 113,398 kg: $d = 1.1640NEWQD^{0.577}$ → d(NEQ =100,000kg) =893.2m

Other PES
distance towards Inhabited Buildings

Similarly the IBD distances for NEQ=80 tons are: 1. 745.9m, 3. 656.2m, 4. 785.3m
and the IBD distances for NEQ=120 tons are: 1. 999.8m, 3. 1020.8m, 4. 992.3m

Attention: The front wall can be oriented towards Inhabited Buildings.

<u>Table 5</u>: IBD for NEQ 80, 100, 120 tons, HD1.1 according to Israel MoD Standard No. 4145 Based on former 6055.9STD, 4145-M

Distance to Inhabited Building (m)				NEWQD (kg)	
PES	Earth Covered Magazine				
	REAR	SIDE	FRONT		
784	655	745	745	80000	NEQ =80,000kg
812	699	778	778	85000	
839	744	811	811	90000	
866	789	843	843	95000	
892	835	875	875	100000	NEQ =100,000kg
943	926	938	938	110000	
978	978	978	978	120000	NEQ =120,000kg

<u>Table 6</u>: IBD for NEQ 80, 100, 120 tons, HD1.1 according to NATO AASTP-1

Q-D TABLE FOR HAZARD DIVISION 1.1

TABLE 1	Q-D TABLE FOR HAZARD DIVISION 1.1		
PES / ES	(a)	(b)	(e)
19	D11 (3270m)[k] D16 (3270m)[lm] D13 (3400m) D14 (3400m)[n]	D11 (3270m)[k] D17 (3270m)[lm] D13 (3400m) D15 (3400m)[n]	D11[k] D13
20	D13 (3400m)[l] D14 (3400m)[n]	D13 (3400m)[l] D14 (3400m)[n]	D13[l] D13 (3400m)

TABLE 1 (PAGE 2) - Q-D TABLE FOR HAZARD DIVISION 1.1

Net Explosives Quantity in kg	Quantity-Distances in metres	
	D13	D14
100 000	1040	
120 000	1100	
140 000	1160	
160 000	1220	
180 000	1260	
200 000	1300	
250 000	1400	
Distance Functions	$D13=5.5Q^{1/2}$ for $Q<4500$ $D13=22.2Q^{1/3}$ for $Q\geq4500$	$D14=14.0Q^{1/3}$

l. see 1.4.1.15.b)	- flying and falling glass, etc.
m. see 1.4.1.15.c)	- 400 m minimum to built up areas
n. see 1.4.6.7.b)	- reduced Q-D for large earth-covered buildings containing NEQ<45 000kg

NEQ=Q =100,000 kg: d =22.2Q$^{(1/3)}$ → <u>d(NEQ =100,000kg)</u> = <u>1030.4m</u>

Similarly, the IBD distances for NEQ=80 and 120 tons are: 956.6m, 1095.0m

NATO IBDs are 1.15-1.23 times greater than DoD IBDs.

Table 7: Expected overpressure from open storage, due to BEC & CONWEP, due to NEQ of 100 tons TNT at 800, 1000, 1200 meters

Distance from the PES (m)	800 meters	1000 meters		1200 meters
	CONWEP (Open Storage)	CONWEP (Open Storage)	(BEC) ECM FRONT, MK83 (*)	CONWEP, (Open Storage)
Arrival time, t_a (ms)	1946	2522	2598.5	3104
Peak Over-Pressure, P_{so} (kPa)	7.31	5.53	4.08	4.36
Reflected Over-Pressure, P_r (kPa)	15.03	11.27	8.16	8.88
Positive Duration, t_o+ (ms)	264	281.2	235.4	295
Positive Incident Impulse, I_s+ (kPa*ms)	846	680	421.6	567
Positive Reflected Impulse, I_r+ (kPa*ms)	1554	1231	747.2	1018

Table 8: Window damage probability (%) at 1000m from the PES according to BEC ver. 4.0 and 6055.09STD

NEQ (TNT) (Tons)	Window Area (sq. meter)	Window Damage Probability (%)
80	0.372	98.4
100	0.372	99.9
120	0.372	100

NEQ (TNT) (Tons)	Window Area (sq. meter)	Window Damage Probability (%)
80	0.186	20.2
100	0.186	26.3
120	0.186	32.3

DoD 6055.09-STD, February 29, 2008, p. 27:

Table C2.T2. Probability of Window Breakage from Incident Pressure

K-FACTOR (ft/lb$^{1/3}$) *Km-FACTOR [m/kg$^{1/3}$]*	Incident Pressure (psi) *[kPa]*	Probability of Breakage (%) for Windows facing PES		
		Window 1	Window 2	Window 3
40 *15.87*	1.2 *8.3*	85	100	100
50 *19.84*	0.9 *6.2*	60	100	100
60 *23.80*	0.7 *4.8*	41	100	100
70 *27.77*	0.6 *4.1*	26	100	100

Window 1: 12" x 24" x 0.088" Float annealed (area = 2 ft^2)
30.5 cm x 61 cm x 0.0.223 cm Float annealed (area = 0.186 m^2)
Window 2: 24" x 24" x 0.088" Float annealed (area = 4 ft^2)
61 cm x 61 cm x 0.0.223 cm Float annealed (area = 0.372 m^2)
Window 3: 42" x 36" x 0.12" Float annealed (area = 10.5 ft^2)
106.7 cm x 91.4 cm x 0.0.395 cm Float annealed (area = 0.975 m^2)

K=1,000m/100,000$^{1/3}$=**21.5m/kg$^{1/3}$**, beyond DoD IBDs (Kmax=19.84m/kg$^{1/3}$)

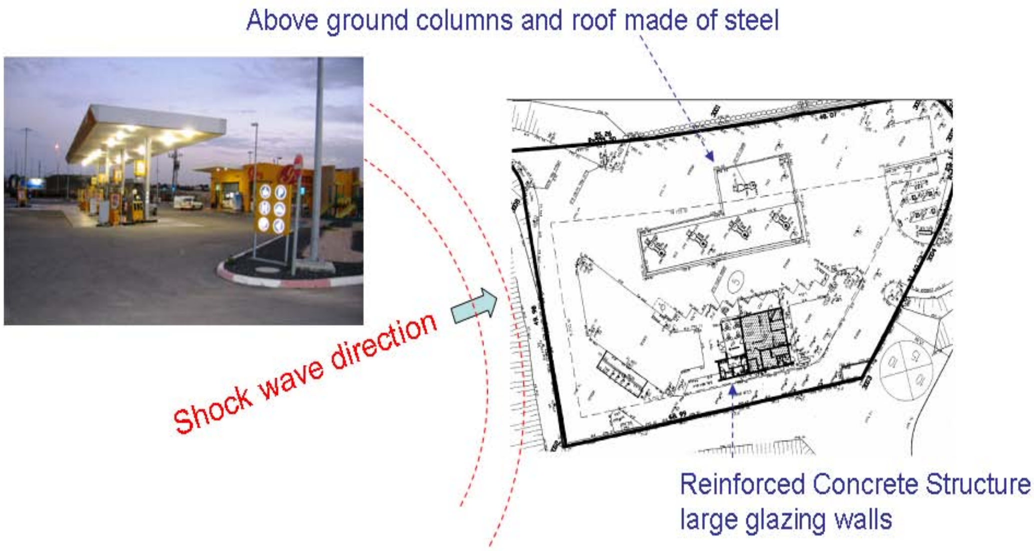


Fig. 4: Gas Station Plan and photograph

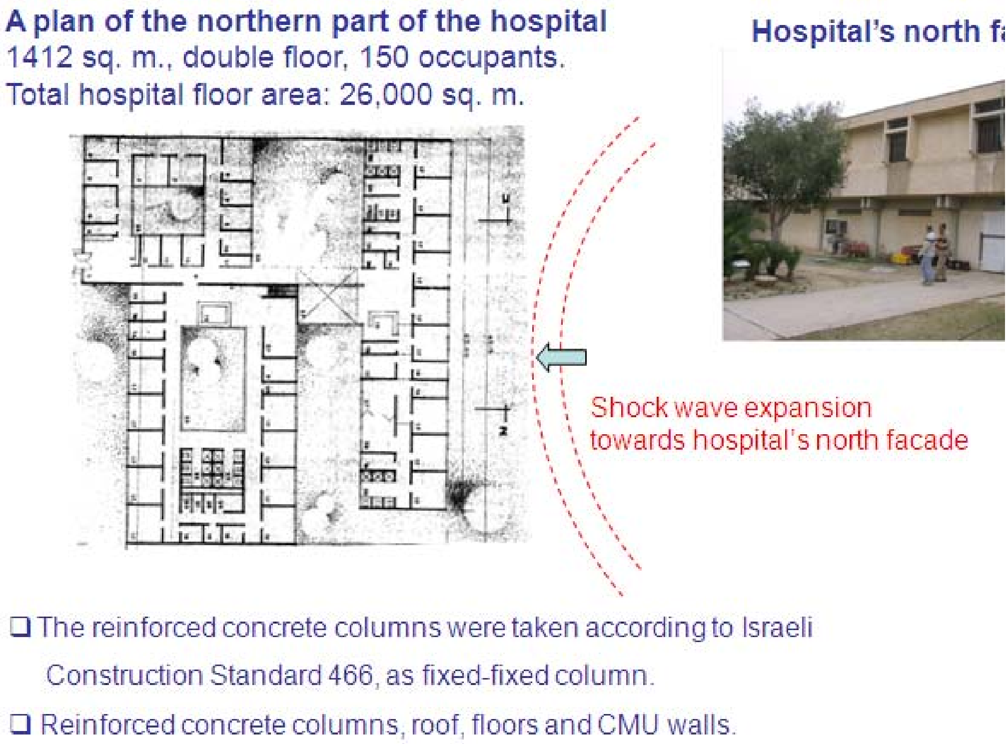
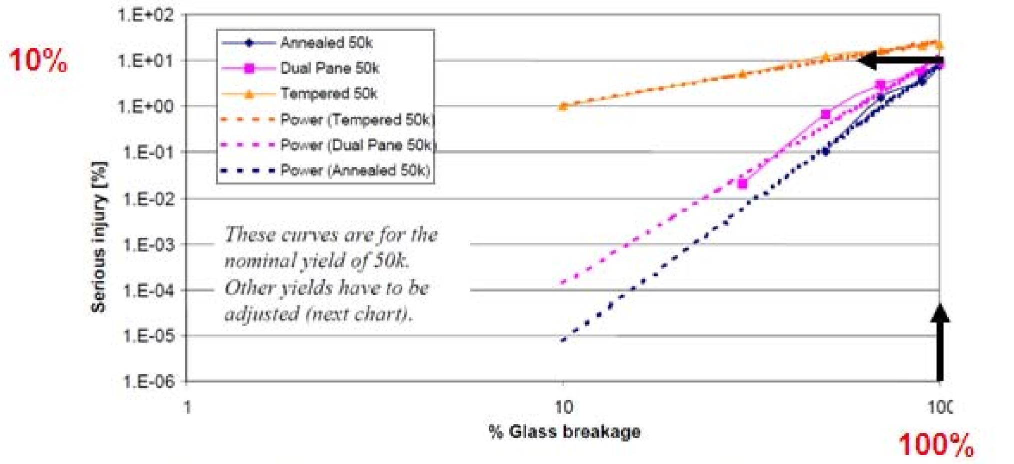


Fig. 5: The hospital facility



Note: Solid lines are data points from the Wilde model. Dashed lines represent the SAFER 3.0 equations.

[TP14] *Figure 5. Serious Injury Given Breakage*

Most of the windows will be broken. The explosion is greater than 50,000 lbs TNT.

At least 10% of serious injuries are expected.

Fig. 6: The meaning of 5.52kPa(*) overpressure on the hospital
100,000 kg TNT, Open Storage, Distance of about 1000m

Findings

Table 9 presents the re-instatement costs for unprotected and upgraded protected hospital. Protective upgrade included strengthening the skeleton, upgrading of windows, and upgrading the interior of the hospital to prevent injuries due to collapse of ceilings, strengthening light and electric end-fixtures. The rest of the building systems remained as in the unprotected alternative.
Table 10 presents the data for the analysis of the consequences of an Explosion Event for the psychiatric hospital facility. It was assumed that the number of occupants of the facility is 150 patients and medical staff. The costs of severely injured, injured and lightly injured are taken according to values acceptable in risk analysis of injuries. The cost of a severely injured is taken to be 33% higher than the cost of a death, and costs of injury is 2/3 the costs of death. The costs of repair of the buildings after the occurrence of an AE explosion event were assumed to be 2.5% of re-instatement cost per sq.m. for the case of upgraded protected structure, and 7.5% of the reinstatement value for the unprotected structure. This was based on protective structures experts' assessment.

Table 9: Reinstatement Costs of Protected vs. Un-Protected Psychiatric Hospital Structure [$/sq. m.]

Building System	Upgraded Protected Structure (Israel HFC, WBDG, FEMA recommendations)	Un-Protected Structure
Structure	426	357
Exterior Envelope	118	59
Interior Finishing	710	610
Water Supply and Sanitary	133	133
Electricity	196	196
HVAC	223	223
Fire Protection	40	40
Lifts	58	58
Communication	81	81
Medical Gas	43	43
Total	2,028	1,800

Table 10: Assessment of Costs at IBD=1,000 m. [$/Facility]

Parameter	Upgraded Protected Structure (Israel HFC, WBDG, FEMA recommendations)	Un-Protected Structure a(b)
Number of Occupants	150	150
Number of victims	0	0
Number of Severely Injured	0	4 (15)
Number of Injured	0	8
Number of Lightly Injured	0	15
Cost of a death [$]	1,000,000	
Cost of Severely Injured [$]	1,333,333	
Cost of Injured [$]	666,667	
Cost of Lightly Injured [$]	22,222	
Total costs of Injuries [$]	0	10,666,667
Total Costs of Damage to Facility [$]	71,588	190,620
Cost of Building Evacuation [$]	0	1,280,000
Total Costs [$]	71,588	12,137,287

Figure 7 depicts the risk expectancy for the two alternatives. The total expectancy of each alternative consists of the reinstatement costs of the hospital per sq. m. and the risk expectancy for each alternative according to equations 1 and 2. The detailed results shown in Table 11 depict that for the case of 10% of the hospital occupants (15 major injuries) the breakeven point between the two alternatives is 1.5E-3.

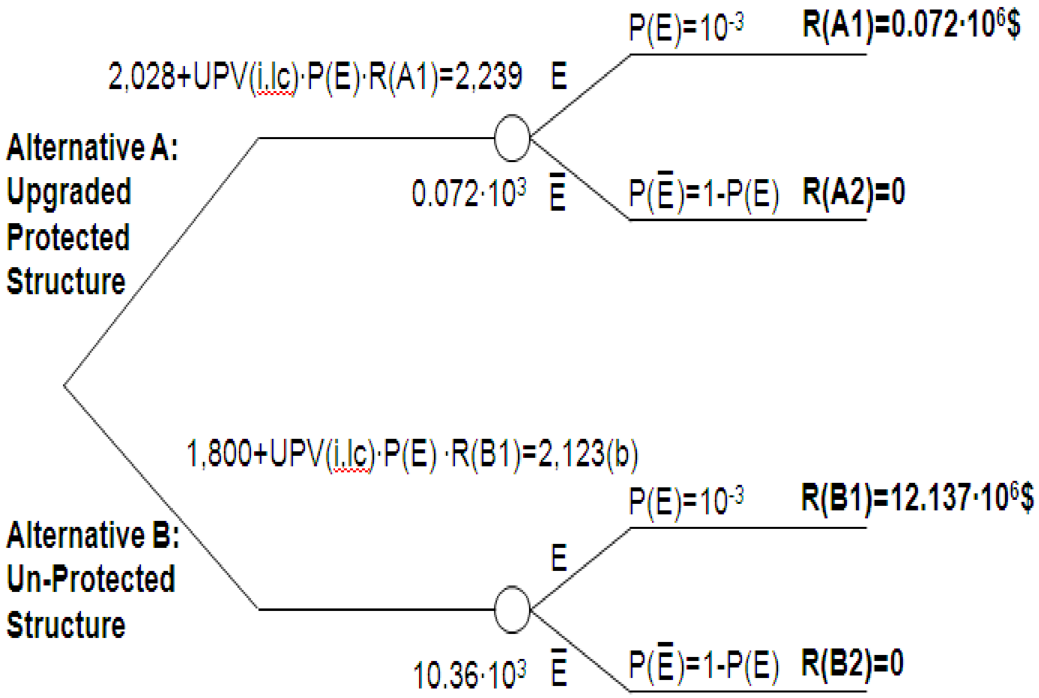


Fig. 7: Decision Tree for comparison between Protected and Unprotected structure for probability of explosion event

Table 11: Total Costs of Construction and Risk for Upgraded Protected and Un-Protected Structure [$/sq. m.]

Annual Probability of AE explosion event	**Upgraded Protected Structure (Israel HFC, WBDG, FEMA recommendations) [$/sq. m.]**	**Un-Protected Structure [$/sq. m.] (a)(4 major injuries)**	**Un-Protected Structure [$/sq. m.] (b)(15 major injuries)**
1E-6	2,238	1,800	1,801
1E-5	2,238	1,801	1,803
1E-4	2,238	1,813	1,832
1E-3	2,239	1,934	2,123
1.5E-3	2,240	2,001	2,285

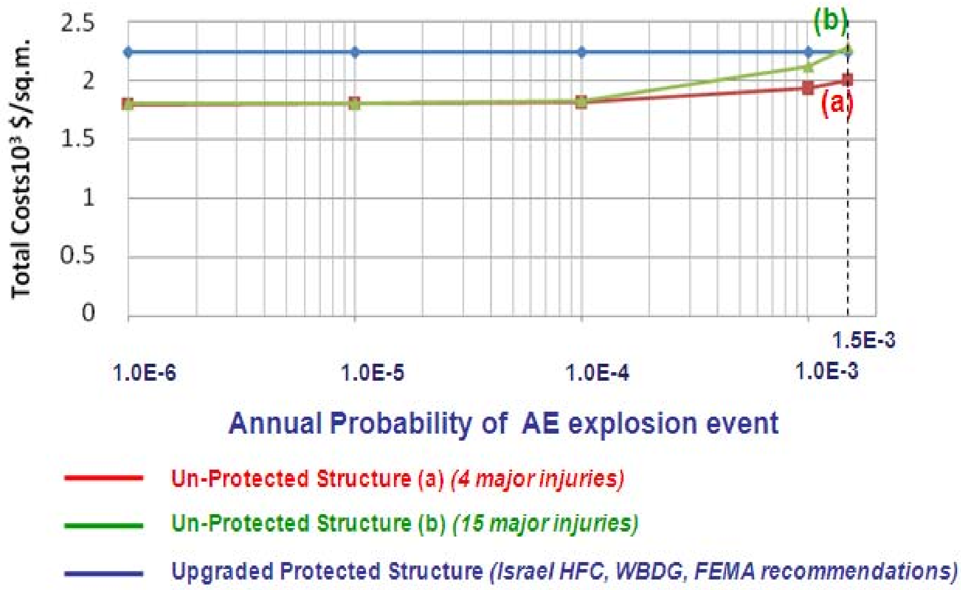


Fig. 8: Total costs of construction and Risk Expectancy for Protected vs. Un-Protected Psychiatric Hospital at IBD of 1000m

Discussion

The case study can represent possible assured IBDs according to US DoD and Israel Mod for AE storage of 80, 100, and 120 tons NEQ of HD 1.1 (ECM or open storage). There are no limit cases where there are vulnerable buildings or critical structures at the ES. The required IBD are up to 1020.8meters only for the 120 tons NEQ.
On the other hand, the NATO manual required distances for vulnerable buildings or critical structures are 1.5-2 times the regular IBD: $33.3Q^{1/3}$-$44.4Q^{1/3}$ and for hospital or schools the minimum distance is at least $44.4Q^{1/3}$.
It means that the hospital should be 2061 m from a 100 tons NEQ or the possible stored AE would be only 11.4 tons!.
The consequences of a 100 tons explosion from an ECM or an open storage at a distance of 1,000 meters from CI, a hospital, were analyzed. The main risk is due to glass fragments, which might cause serious injuries to about 10% of the hospital occupants.
According to WBDG, FEMA and to Israeli HFC recommendation the window glazing will be protected (film, catch bar). In order to avoid internal risk to the occupants and medical equipment failure, the end fixtures at the hospital will be strengthened.
These basic means can guarantee that none of the hospital occupants will be hurt or wounded. The extra cost for this upgraded protection can be beneficial when we compare two alternatives: unprotected building to upgraded protected building for an accidental explosion probability of about 1.5e-3. If the building exists more than 50 years than the above-mentioned probability decreases.
If the building is more crowded, and/or the building retains more blast, i.e. a high rise building, than blast effect can be enhanced while causing greater damages and risk.

The protective solutions for the case of vulnerable buildings, public important, and CIs can be as follows:

Upgrading protective level of the buildings at the ES, mainly window glazing and end fixtures;

- Decreasing the allowed AE storage;
- Moving or placing the vulnerable buildings, public important, and CIs at NATO distances.

Concluding Remarks

The research may be summarized in the following main points:

1. Ammunition Storage Standards and manuals do not prevent major economical consequences to ES structures, and CIs.

2. Severe injuries are likely to occur, mainly due to glass fragments.

3. US DoD and Israel MoD storage standards concerning IBD to CIs, and sensitive or essential facilities, should be reviewed and revised.

4. In light of the findings, CIs located at the ES, should be protected.

5. Protected CIs located at ES will reduce the risk to the occupants significantly, and help maintaining their continuous performance.

The ERA (Explosion Risk Assessment) model can contribute to an improved policy of ammunition storage; and to provide analytical approach to update the actual standards and determination of IBD according to risk expectancy and Benefit to Cost Ratio, rather than according to safety criteria only.

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A Risk Management Model of Urban Areas near Ammunition Storage

Ornai D., Shohet I.M., and Ben Salomon O.

34th **DDESB Seminar**

Portland, Oregon, July 13-15, 2010

The research project was co-supervised by Mr. Avi Ronen, Israeli Ministry of Interior

Contents

- Overview of the research project.
- Presenting the **PES** location and its surrounding **ES** at urban area**,** in particular a Critical Infrastructure (**CI),** a hospital.
- Comparison of Ammunition & Explosives Storage Standards and manuals regarding to the research subject.
- Explosion effects on the **ES**: blast, fragments, debris, ground shock, and secondary fragments: glazing fragments.
- **CI**'s Explosion Risk Assessment: **ERA** (using TP14, SAFER methodology).
- Summary.

Overview of the research

- Stored Ammunition and Explosives, **AE,** might be exploded, due to accident, terror or war activities while causing severe hazards to nearby structures, **CI**s, and their occupants.

- The research included: a review of **AE** storage standards and manuals (US, NATO, Israel) for the case of Hazard Division - HD 1.1 *(Mass Explosion),* when there is a close urban area with both regular inhabited building and **CIs**, i.e. a hospital.

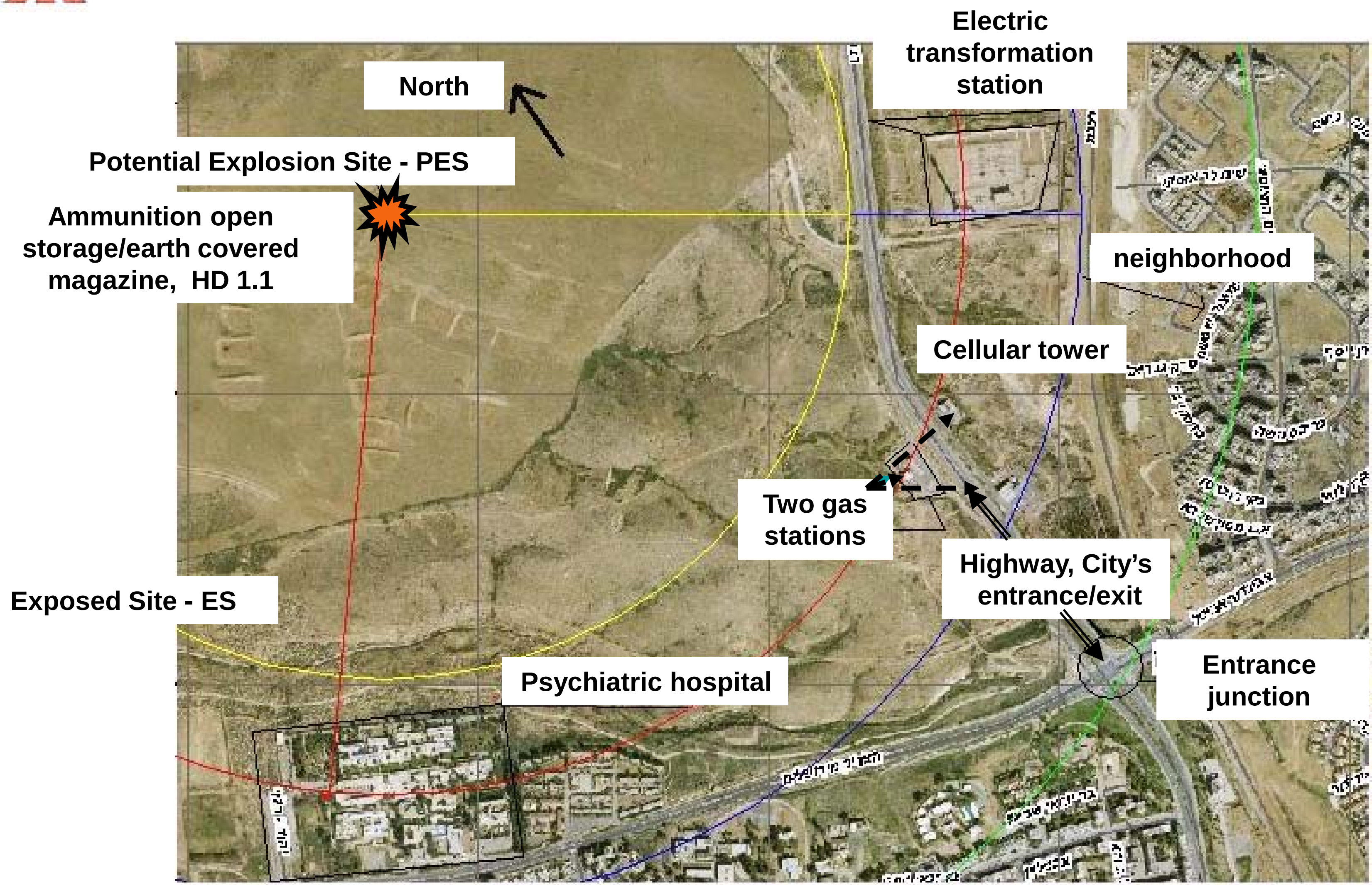
- Case study: a PES with **NEQ**, of 100 tons of TNT. The PES is located according to US and Israel standards and manuals just 800 to 1200 meters from peripheral areas of a city and **CIs**: *Psychiatric hospital, Gas stations, etc.*

- Analysis of explosion consequences.

- Sensitivity analysis to NEQ of 80, 100, and 120 tons of TNT and for distances of 800, 1000, and 1200 meters.

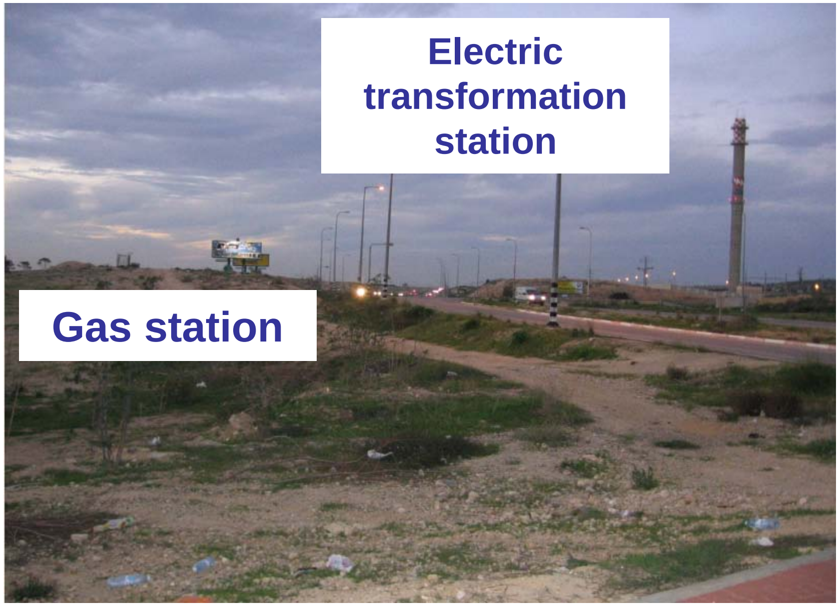
- Examination of Alternative Design of the hospital: Upgraded Protected vs. Un-Protected.

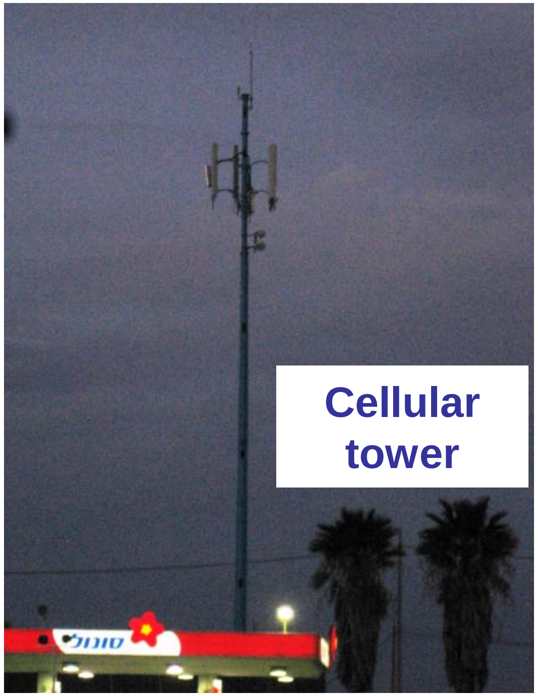
The Hypothetical area of explosion



Explosion Ranges:
Yellow---- 800m, Red----1000m, Blue----1200m, Green----1500m

Buildings and Critical Infrastructures, CIs at the ES





Research Method

Alternative Design

↓

Analysis of Explosion Consequences – Structure, Vulnerability

↓

Economic Analysis of Consequences

↓

ERA – Explosion Risk Assessment (*)

↓

Structural Re-Engineering

(*) Based upon P.R.A.– Probabilistic Risk Assessment

Quantity – Distance Demands and Peak Over-Pressure for HD1.1

IBD- Inhabited building distances (*)

High Traffic Density: If routes have 10,000 or more cars per day then IBD criteria is required

Ammunition Storage Standard, Manual	6055.09STD, 4145.24-M *for all buildings*	NATO AASTP-1 *for regular buildings*	Israel MoD Standard 4145 *for regular buildings* (**)
Blast Peak Overpressure	**6.2-8.3 kPa** [0.9-1.2 psi]	**5 kPa** [=0.05bar=0.7psi]	**6-8.5 kPa** [0.85-1.2 psi]
Quantity (Weight) - Distance Formulas for IBD	Distance From PES: **$15.87Q^{1/3}$-$19.84Q^{1/3}$[kg,m]** $40W^{1/3}$ ft - $50W^{1/3}$ [lb,ft] W< 100,000 lbs [45,400kg] ➔ $40W^{1/3}$ [lb,ft] **[$15.87Q^{1/3}$] [kg,m]** W> 250,000 lbs [113,400kg] ➔ $50W^{1/3}$ [lb,ft] **[$19.84Q^{1/3}$] [kg,m]**	Distances from Open Stacks and Light structures **22.2 $Q^{1/3}$[kg,m]** Distances from Earth Covered Magazines ECMs: **Side=18.0$Q^{1/3}$[kg,m]** **Rear=14.0$Q^{1/3}$[kg,m]** **Front is not an option**	Distance From PES: **$16Q^{1/3}$-$20Q^{1/3}$ [kg,m]** Q< [45,400kg] ➔**$16Q^{1/3}$[kg,m]** Q> [113,400kg] ➔ **$20Q^{1/3}$[kg,m]**

(*) According to all standards for large amounts of NEQ **Blast Over Pressure governs**, rather than fragment or debris.

(**) For 6 or less building units or apartments per 1000 square meter at the ES, otherwise **D=22.2 $Q^{1/3}$[kg,m]**

NATO enlarged IBD according to vulnerable construction and public importance

1.3.7.6. *Protection Level 44.4 $Q^{1/3}$ to 33.3 $Q^{1/3}$ - Open Stacks and Light Structures*

Large facilities of special construction of importance including:

- Large factories of vulnerable construction.
- Multi-storey office or apartment buildings of vulnerable construction.
- Public buildings and edifices of major value.
- Large educational facilities of vulnerable construction.
- Large hospitals.
- Major traffic terminals (e.g. large railway stations, airports etc.)
- Major public utilities (e.g. gas, water, electricity works).

Facilities of vulnerable construction used for mass meetings:

- Assembly halls and fairs.
- Exhibition areas.
- Sports stadiums.

Built-up areas which are both large and densely developed.

Blast peak overpressure	2 kPa- 3 kPa = 0.02-0.03[bar] = =0.28-0.43[psi]
Quantity-Distance Formula	**33.3 $Q^{1/3}$ to 44.4 $Q^{1/3}$**

According to page I-3-13 for schools and hospitals, IBD $>$ 44.4 $Q^{1/3}$

HD1.1 Quantity – Distances, IBD

due to Fragments, Debris, Ground Shock & Motions

Parameter	Ammunition Storage Standards		
	6055.09STD 4145.26-M	NATO AASTP-1	Israel MoD Standard 4145
Fragments, Debris	1 hazardous fragment with energy of 78lb*ft at each 56 square meter (600 square ft.), Minimum distance 400 m.		
Ground Shock & Motions	No Restriction	Restricted, i.e. for dry sand: D(tamped charge) $=\mathbf{5.5Q^{1/3}}$ D(loading density≤50kg/m³)$=\mathbf{2.8Q^{1/3}}$	No Restriction

Table AP2.T1. HD 1.1 IBD and PTRD (Table C9.T1.) (continued)

NEWQD	IBD From:			
	ECM			Other
	Front[1,2]	Side[1]	Rear[3]	PES[4]
(lbs)	(ft)	(ft)	(ft)	(ft)
[kg]	*[m]*	*[m]*	*[m]*	*[m]*
100,000	1,625	1,625	1,250	1,857
45,359.0	*495.0*	*495.0*	*381.0*	*565.6*
150,000	2,177	2,177	1,804	2,346
68,038.5	*663.5*	*663.5*	*550.0*	*715.2*
200,000	2,680	2,680	2,469	2,770
90,718.0	*816.8*	*816.8*	*752.5*	*844.4*
250,000	3,149	3,149	3,149	3,151
113,397.5	*959.8*	*959.8*	*959.8*	*960.4*
300,000	3,347	3,347	3,347	3,347
136,077.0	*1,020.5*	*1,020.5*	*1,020.5*	*1,020.5*
500,000	3,969	3,969	3,969	3,969
226,795.0	*1,209.9*	*1,209.9*	*1,209.9*	*1,209.9*

Attention

The front wall can be oriented towards Inhabited Buildings.

Notes for Table AP2.T1.:

1. 100,000 lbs < NEWQD $\leq$ 250,000 lbs: $d = 0.3955 NEWQD^{0.7227}$ → d(NEW =220,458.6lb) =876.7m
45,359 kg < NEWQD $\leq$ 113,398 kg: $d = 0.2134 NEWQD^{0.7227}$ → d(NEQ =100,000kg) =876.4m

ECM Front or Side
distance towards Inhabited Buildings

3. 100,000 lbs < NEWQD $\leq$ 250,000 lbs: $d = 0.004125 NEWQD^{1.0898}$ → d(NEW =220,458.6lb)=836.8m
45,359 kg < NEWQD $\leq$ 113,398 kg: $d = 0.002976 NEWQD^{1.0898}$ → d(NEQ =100,000kg) =836.8m

ECM Rear
distance towards Inhabited Buildings

4. 100,000 lbs < NEWQD $\leq$ 250,000 lbs: $d = 2.42 NEWQD^{0.577}$ → d(NEW =220,458.6lb)=893.2m
45,359 kg < NEWQD $\leq$ 113,398 kg: $d = 1.1640 NEWQD^{0.577}$ → d(NEQ =100,000kg) =893.2m

Other PES
distance towards Inhabited Buildings

Similarly the IBD distances for: NEQ=80 tons are: 1. 745.9m, 3. 656.2m, 4. 785.3m
NEQ=120 tons are: 1. 999.8m, 3. 1020.8m, 4. 992.3m

Israel MoD Standard 4145 IBDs

Based on former 6055.9STD, 4145-M

PES	Distance to Inhabited Building (m)			NEWQD (kg)
	Earth Covered Magazine			
	REAR	SIDE	FRONT	
784	655	745	745	80000
812	699	778	778	85000
839	744	811	811	90000
866	789	843	843	95000
892	835	875	875	100000
943	926	938	938	110000
978	978	978	978	120000

NEQ =80,000kg

NEQ =100,000kg

NEQ =120,000kg

NATO AASTP-1 IBDs

(for regular buildings)

ANNEX I-A
AASTP-1
(Edition 1)

Q-D TABLE FOR HAZARD DIVISION 1.1

TABLE 1	Q-D TABLE FOR HAZARD DIVISION 1.1		
PES / ES	(a)	(b)	(e)
19	D11 (≥270m)[k] D16 (≥270m)[kn] D13 (≥400m) D14 (≥400m)[n]	D11 (≥270m)[k] D17 (≥270m)[kn] D13 (≥400m) D15 (≥400m)[n]	D11[k] D13
20	D13 (≥400m)[l] D14 (≥400m)[ln]	D13 (≥400m)[l] D14 (≥400m)[ln]	D13[l] D13 (≥400m)

TABLE 1 (PAGE 2) - Q-D TABLE FOR HAZARD DIVISION 1.1

Net Explosives Quantity in kg	Quantity-Distances in metres	
	D13	D14
100 000	1040	
120 000	1100	
140 000	1160	
160 000	1220	
180 000	1260	
200 000	1300	
250 000	1400	
Distance Functions	$D13=5.5Q^{1/2}$ for Q<4500 $D13=22.2Q^{1/3}$ for Q≥4500	$D14=14.0Q^{1/3}$

l. see 1.4.1.15.b)	- flying and falling glass, etc.
m. see 1.4.1.15.c)	- 400 m minimum to built up areas
n. see 1.4.6.7.b)	- reduced Q-D for large earth-covered buildings containing NEQ<45 000kg

NEQ=Q =100,000 kg: d =22.2Q$^{(1/3)}$ → d(NEQ =100,000kg) =1030.4m

Similarly, the IBD distances for NEQ=80 and 120 tons are: 956.6m, 1095.0m

NATO IBDs are 1.15-1.23 times greater than DoD IBDs.

Expected overpressure from open storage, due to BEC & CONWEP

For the Case Study: NEQ of 100 tons TNT

Distance from the PES (m)	800 meters	1000 meters		1200 meters
	CONWEP (Open Storage)	**CONWEP** (Open Storage)	**(BEC) ECM FRONT, MK83 (*)**	**CONWEP** (Open Storage)
Arrival time, t_a (ms)	1946	2522	2598.5	3104
Peak Over-Pressure, P_{so} (kPa)	7.31	5.53	4.08	4.36
Reflected Over-Pressure, P_r (kPa)	15.03	11.27	8.16	8.88
Positive Duration, t_o+ (ms)	264	281.2	235.4	295
Positive Incident Impulse, I_s+ (kPa*ms)	846	680	421.6	567
Positive Reflected Impulse, I_r+ (kPa*ms)	1554	1231	747.2	1018

(*) Total NEQ 100,000 kg TNT

Window damage probablity (%) at 1000m from the PES

according to BEC ver. 4.0

NEQ (TNT) (Tons)	Window Area (sq. m.)	Window Damage Probability (%)
80	0.372	98.4
100	0.372	99.9
120	0.372	100

NEQ (TNT) (Tons)	Window Area (sq. m.)	Window Damage Probability (%)
80	0.186	20.2
100	0.186	26.3
120	0.186	32.3

DoD 6055.09-STD, February 29, 2008, p. 27:

Table C2.T2. Probability of Window Breakage from Incident Pressure

K-FACTOR ($ft/lb^{1/3}$) *Km-FACTOR [$m/kg^{1/3}$]*	Incident Pressure (psi) *[kPa]*	Probability of Breakage (%) for Windows facing PES		
		Window 1	Window 2	Window 3
40 *15.87*	1.2 *8.3*	85	100	100
50 *19.84*	0.9 *6.2*	60	100	100
60 *23.80*	0.7 *4.8*	41	100	100
70 *27.77*	0.6 *4.1*	26	100	100

Window 1: 12" x 24" x 0.088" Float annealed (area = 2 ft^2)
30.5 cm x 61 cm x 0.0.223 cm Float annealed (area = 0.186 m^2)

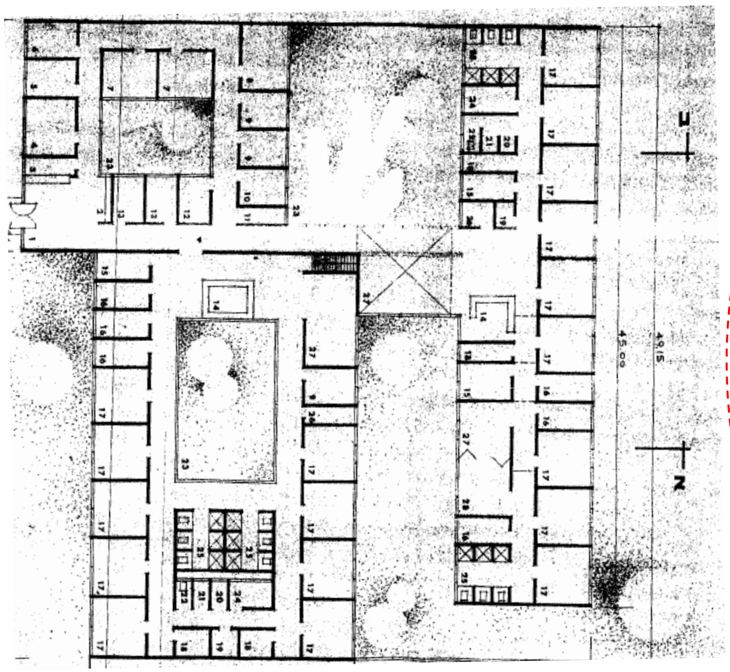
Window 2: 24" x 24" x 0.088" Float annealed (area = 4 ft^2)
61 cm x 61 cm x 0.0.223 cm Float annealed (area = 0.372 m^2)

Window 3: 42" x 36" x 0.12" Float annealed (area = 10.5 ft^2)
106.7 cm x 91.4 cm x 0.0.395 cm Float annealed (area = 0.975 m^2)

K=1,000m/100,000$^{1/3}$=**21.5m/kg$^{1/3}$**,
beyond DoD IBDs (K_{max}=19.84m/kg$^{1/3}$)

CI, The hospital structure

A plan of the northern part of the hospital
1412 sq. m., double floor, 150 occupants.
Total hospital floor area: 26,000 sq. m.



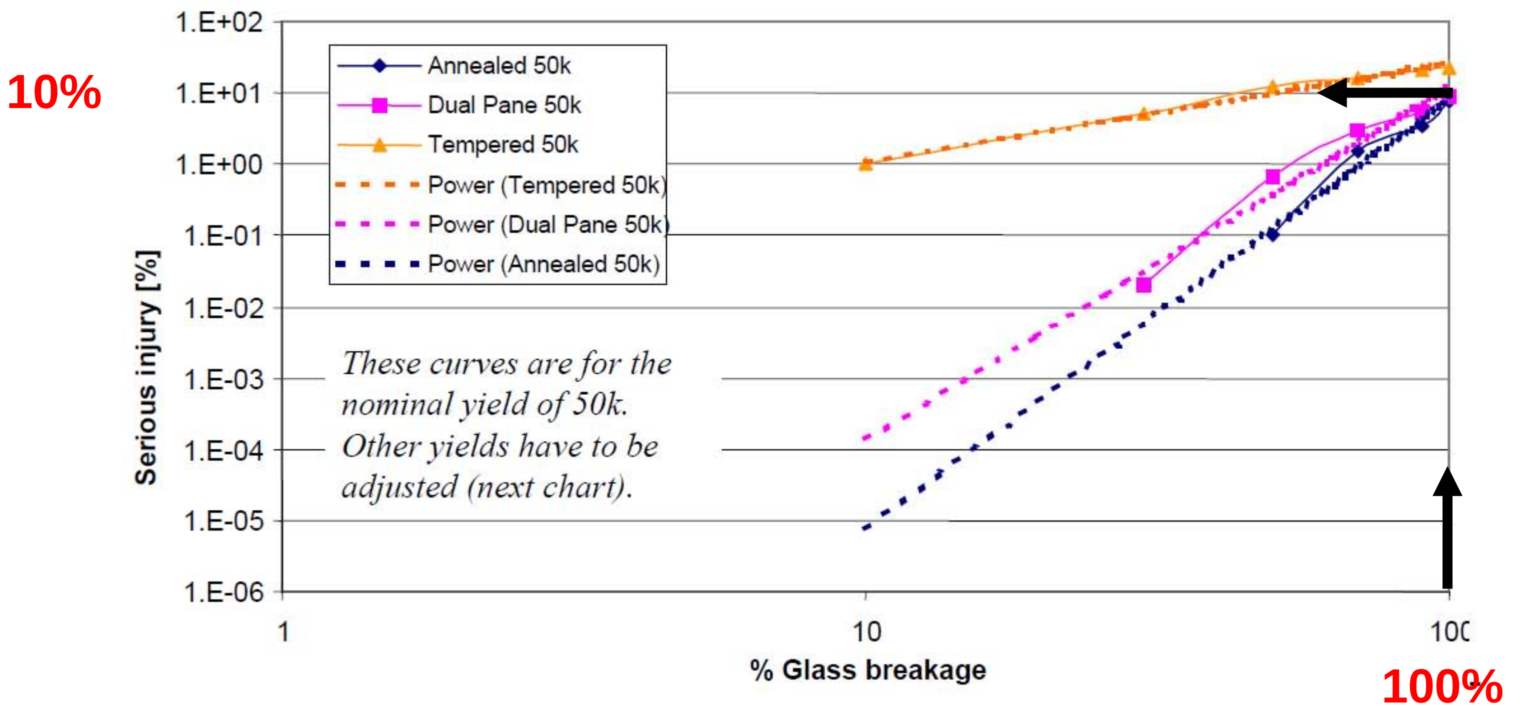
Hospital's north facade

Shock wave expansion
towards hospital's north facade

- The reinforced concrete columns were taken according to Israeli Concrete Standard 466, as fixed-fixed column.
- Reinforced concrete columns, roof, floors and CMU walls.

The meaning of 5.53kPa(*) overpressure on the hospital

NEQ=100,000 kg TNT, Open Storage, Distance of about 1000 m.



Note: Solid lines are data points from the Wilde model. Dashed lines represent the SAFER 3.0 equations.

[TP14] *Figure 5. Serious Injury Given Breakage*

Most of the windows will be broken. The explosion is greater than 50,000 lbs TNT.

At least 10% of serious injuries are expected.

Reinstatement Costs of Upgraded Protected vs. Un-Protected Psychiatric Hospital Structure [$/sq. m.]

Building System	Upgraded Protected Structure *(Israel HFC , WBDG, FEMA recommendations)*	Un-Protected Structure
Structure	426	357
Exterior Envelope	118	59
Interior Finishing	710	610
Water Supply and Sanitary	133	133
Electricity	196	196
HVAC	223	223
Fire Protection	40	40
Lifts	58	58
Communication	81	81
Medical Gas	43	43
Total	**2,028**	**1,800**

Assessment of Costs at IBD=1,000 m. [$/Facility]

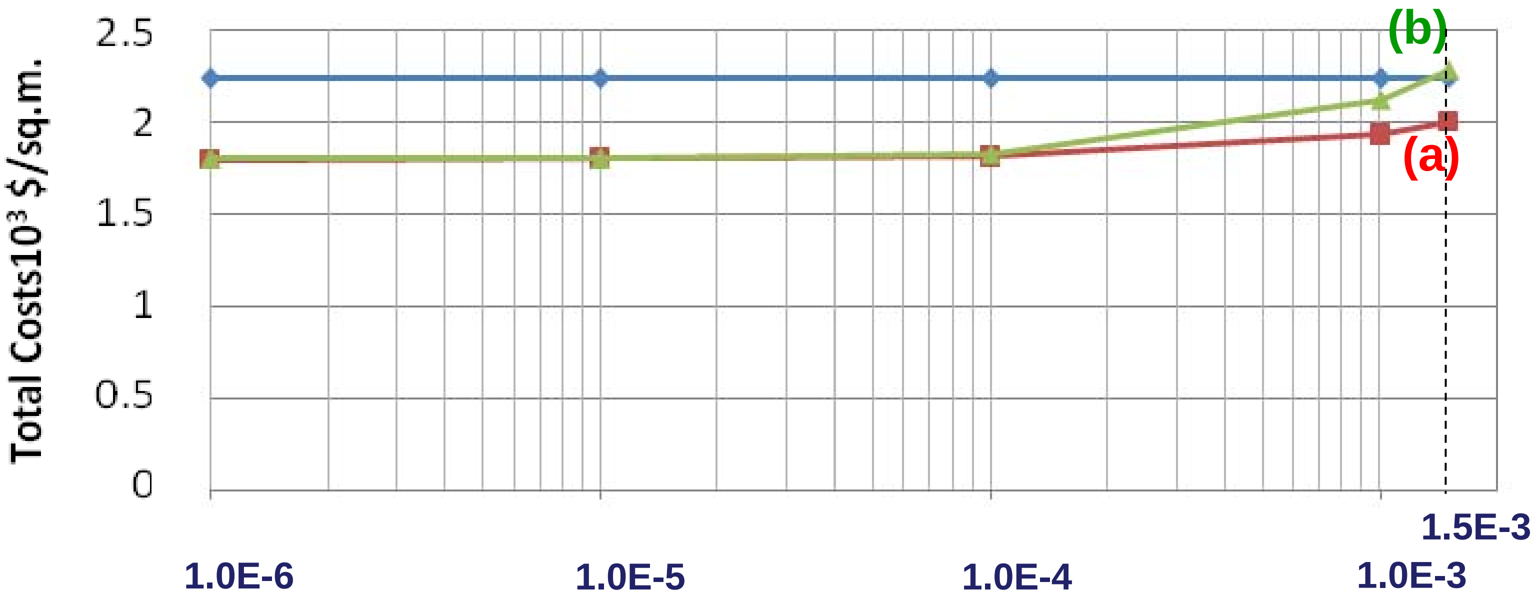
Parameter	Upgraded Protected Structure (*Israel HFC , WBDG, FEMA recommendations)*	Un- Protected Structure a (b)
Number of Occupants	**150**	**150**
Number of victims	**0**	**0**
Number of Severely Injured	**0**	**4 (15)**
Number of Injured	**0**	**8**
Number of Lightly Injured	**0**	**15**
Cost of a death [$]	**1,000,000**	
Cost of a Severely Injured [$]	**1,333,333**	
Cost of a Injured [$]	**666,667**	
Cost of a Lightly Injured [$]	**22,222**	
Total costs of Injuries [$]	**0**	**10,666,667**
Total Costs of Damage to Facility [$]	**71,588**	**190,620**
Cost of Building Evacuation [$]	**0**	**1,280,000**
Total Costs [$]	**71,588**	**12,137,287**

(a) - *4 major injuries*
(b) *-15 major injuries*

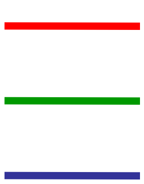
Total Costs of Construction and Risk for Protected and Un-Protected Structures following TP14, SAFER methodology [$/sq. m.]

Annual Probability of AE explosion event	Upgraded Protected Structure *(Israel HFC , WBDG, FEMA recommendations)* [$/sq. m.]	Un-Protected Structure (a) *(4 major injuries)*	Un-Protected Structure (b) *(15 major injuries)*
1.0E-06	2,238	1,800	1,801
1.0E-05	2,238	1,801	1,803
1.0E-04	2,238	1,813	1,832
1.0E-03	2,239	1,934	2,123
1.5E-03	2,240	2,001	2,285

Total costs of construction and Risk Expectancy for Protected vs. Un-Protected Psychiatric Hospital at 1000m IBD



Annual Probability of AE explosion event



Un-Protected Structure (a) ***(4 major injuries)***

Un-Protected Structure (b) ***(15 major injuries)***

Upgraded Protected Structure ***(Israel HFC, WBDG, FEMA recommendations)***

Concluding Remarks

1. Ammunition Storage Standards do not prevent major economic damages to vulnerable ES structures, public important facilities, and **CI**s.

2. Severe injuries are likely to happen, mainly due to glass fragments.

3. It is recommended that US DoD and Israel MoD storage standards and manuals concerning IBD to **CI**s, and vulnerable or essential facilities will be reviewed and revised.

4. In light of the findings, vulnerable structures, public important facilities, and **CI**s located at ES, should be protected.

5. Protected **CI**s located at ES reduce the risk to the occupants significantly, and help maintaining their continuous performance.

6. The **ERA** model can be very useful for proofing the safety and continuous performance of **CI**s, considering risks and the economic consequences.

Thank you for your attention!

Questions ?

Decision Tree for comparison between Upgraded Protected and Un-protected structure for probability of AE explosion event